Claims:

1. A spread spectrum waveform generator comprising:
   (a) a photonic oscillator comprising a multi-tone optical comb generator for generating a series of RF comb lines on an optical carrier;
   (b) an optical heterodyne synthesizer, the optical heterodyne synthesizer including first and second phase-locked lasers, the first laser feeding the multi-tone optical comb generator and the second laser comprising a single tone laser whose output light provides a frequency translation reference; and
   (c) a photodetector for heterodyning the frequency translation reference with the series of RF comb lines on the optical carrier generated by the photonic oscillator to generate a spread spectrum waveform.

2. The spread spectrum waveform generator of claim 1 wherein said single tone laser comprises a wavelength-tunable single tone laser.

3. The spread spectrum waveform generator of claim 2, wherein said spread spectrum waveform generator comprises an agile spread spectrum waveform generator providing an agile spread spectrum waveform.

4. The spread spectrum waveform generator of claim 1, wherein said single tone laser comprises a wavelength-modulated single tone laser and said optical heterodyne synthesizer further comprises a third laser source, said third laser source generating at least a fixed tone and a frequency-modulated tone.

5. The spread spectrum waveform generator of claim 4, wherein said spread spectrum waveform generator comprises a frequency-modulated spread spectrum waveform generator providing a frequency-modulated spread spectrum waveform.

6. The spread spectrum waveform generator of claim 1 wherein the photonic oscillator comprises multiple loops including:

(i) a first optical delay line in a first loop for spacing a comb generated by the a multi-tone optical comb generator;

(ii) a second optical delay line in a second loop for noise reduction, the second delay line being longer than the first optical delay line;

(iii) at least one photodetector connected to the first and second delay lines; and

(iv) an optical intensity modulator in a loop portion common to the first and second loops for driving the first and second optical delay lines.

7. The spread spectrum waveform generator of claim 6 wherein the loop common portion further includes an amplifier and a band pass filter.

8. The spread spectrum waveform generator of claim 7 wherein the amplifier is an electronic amplifier.

9. The spread spectrum waveform generator of claim 6 wherein the loop common portion further includes a band pass filter and wherein at least one of the first and second loops includes an optical amplifier therein.

10. The spread spectrum waveform generator of claim 6 further including means for compensating for environmental changes affecting the delays provided by at least one of the first and second optical delay lines.

11. The spread spectrum waveform generator of claim 10 wherein the means for compensating for environmental changes affecting the delays provided by at least one of the first and second optical delay lines comprises an apparatus for adjusting the length and/or refractive index of at least one of the first and second optical delay lines and a feedback circuit including a tone selection filter to the loop common portion.

12. The spread spectrum waveform generator of claim 11, wherein said feedback circuit further comprises a frequency/phase discriminator for comparing the output of the tone selection filter with a reference signal, an output of the discriminator being operatively coupled to the adjusting apparatus.

13. The spread spectrum waveform generator of claim 11, wherein said feedback circuit further comprises a mixer for mixing the output of the tone selection filter with a reference signal, an output of the mixer being operatively coupled to the adjusting apparatus

14. The spread spectrum waveform generator of claim 11 wherein the tone selection filter is coupled to the optical intensity modulator.

15. The spread spectrum waveform generator of claim 14 wherein the optical intensity modulator is an electro-absorption modulator having an electrical output coupled to the tone selection filter.

16. The spread spectrum waveform generator of claim 11 wherein the adjusting apparatus adjusts the length and/or refractive index of both of the first and second optical delay lines.

17. The spread spectrum waveform generator of claim 10 wherein the means for compensating for environmental changes comprises a phase shifter disposed in the loop common portion and a feedback circuit including a tone selection filter coupled to the loop common portion.

18. The spread spectrum waveform generator of claim 17, wherein the feed back circuit further comprises a frequency/phase discriminator for comparing the output of the tone selection filter with a reference signal, an output of the discriminator being operatively coupled to the phase shifter.

19. The spread spectrum waveform generator of claim 17, wherein the feed back circuit further comprises a mixer for mixing the output of the tone selection filter with a reference signal, an output of the mixer being operatively coupled to the phase shifter.

20. The spread spectrum waveform generator of claim 17 wherein the tone selection filter is coupled to the optical intensity modulator.

21. The spread spectrum waveform generator of claim 12 wherein the optical intensity modulator is an electro-absorption modulator having an electrical output coupled to the tone selection filter.

22. The spread spectrum waveform generator of claim 2 further including an injection seeding circuit for seeding the photonic oscillator.

23. The spread spectrum waveform generator of claim 2 wherein the second optical delay line is more than 40 times longer than the first optical delay line.

24. The spread spectrum waveform generator of claim 2 further including an optical intensity modulator, the optical intensity modulator being responsive to an RF input signal and to the series of RF comb lines on the optical carrier generated by the photonic oscillator for generating an optical signal which is applied to said photodetector.

25. The spread spectrum waveform generator of claim 2 further including an optical coupler connected to receive the series of RF comb lines on the optical carrier generated by the photonic oscillator and the frequency translation reference generated by the second laser,

26. The spread spectrum waveform generator of claim 25, wherein the optical coupler is connected either upstream or downstream of the optical intensity modulator which is responsive to an RF input signal.

27. The spread spectrum waveform generator of claim 26 wherein the RF input signal includes a pulsed code or polyphased codes.

28. The spread spectrum waveform generator of claim 4, wherein the single tone laser has a free-running wavelength that differs from the wavelengths of the frequency modulated tone of the third laser source by an amount that is smaller than an injection locking bandwidth of the single tone laser.

29. The spread spectrum waveform generator of claim 1 wherein the photonic oscillator comprises:

a first optical branch comprising a first optical delay element;

a second optical branch comprising a main optical fiber having a forward direction of light propagation;

a third optical branch, said third optical branch providing a Stokes beam to said second optical branch, said Stokes beam propagating in said main optical fiber in a direction opposite to said forward direction of light propagation; and

a common path, said common path comprising:

an optical portion having an optical modulator providing an optical signal to said first optical branch, said second optical branch, and said third optical branch; and

an electrical portion having at least one photodetector coupled to said first optical branch and said second optical branch, said at least one photodetector producing an electrical signal coupled to said optical modulator.

30. The spread spectrum waveform generator of claim 29, wherein said electrical portion comprises:

a first photodetector coupled to said first optical branch;

a second photodetector coupled to said second optical branch;

an electrical combiner coupled to said first photodetector and said second photodetector and producing a combined electrical output; and

a bandpass filter receiving said combined electrical output and providing a filtered electrical signal to said optical modulator.

31. The spread spectrum waveform generator of claim 29 wherein said common path further comprises at least one element of the group of elements consisting of an electrical amplifier, an optical amplifier, an electrical phase shifter, and an optical phase shifter.

32. The spread spectrum waveform generator of claim 29 wherein said common path further comprises a variable optical coupler, said variable optical coupler having an input receiving said optical signal, and having a first adjustable output coupled to said first optical branch, a second adjustable output coupled to said second optical branch, and a third adjustable output.

33. The spread spectrum waveform generator of claim 29, wherein at least one optical branch of said first and second optical branches further comprises at least one element of the group of elements consisting of an optical amplifier and a variable optical attenuator.

34. The spread spectrum waveform generator of claim 29, wherein said first optical delay element comprises optical fiber.

35. The spread spectrum waveform generator of claim 29, wherein said third optical branch comprises an optical notch filter that reduces a component of Stokes light that is generated in said Stokes beam.

36. The spread spectrum waveform generator of claim 29, wherein said third optical branch comprises an optical notch filter that reduces the amount of power of said optical carrier coupled into said third optical branch.

37. The spread spectrum waveform generator of claim 29, wherein said Stokes beam is produced by stimulated Brillouin scattering in said main optical fiber and said main optical fiber has an input and an output and said third optical branch comprises:

an optical amplification path, said optical amplification path having an input and an output;

a first optical circulator, said first optical circulator coupling said optical signal to said input of said main optical fiber and coupling said Stokes beam to said input of said optical amplification path; and

a second optical circulator, said second optical circulator coupling said output of said optical amplification path to said main optical fiber and coupling said output of said main optical fiber to said at least one photodetector.

38. The spread spectrum waveform generator of claim 37, wherein said optical amplification path comprises one or more optical amplifiers or one or more optical amplifiers and one or more variable optical attenuators.

39. The spread spectrum waveform generator of claim 29, wherein said main optical fiber has an input and an output and wherein said second optical branch further comprises an optical splitter having a first splitter output and a second splitter output, the second splitter output directing said optical signal to said input of said main optical fiber, and wherein said third optical branch comprises:

an optical amplification path having an input and an output;

an optical path producing said Stokes beam by stimulated Brillouin scattering;

a first optical circulator having at least three ports, wherein a first port of said first optical circulator is coupled to said first splitter output and a second port of said first optical circulator coupled to said input of said optical amplification path, and a third port of said first optical circulator is coupled to said optical path producing said Stokes beam, said first optical circulator directing said optical signal to said optical path producing said Stokes beam and directing said Stokes beam to said optical amplification path; and,

a second optical circulator, said second optical circulator coupling said output of said optical amplification path to said main optical fiber and coupling said output of said main optical fiber to said at least one photodetector.

40. The spread spectrum waveform generator of claim 39, wherein said optical path producing said Stokes beam comprises:

a loop of optical fiber; and

a 2 x 2 optical coupler having at least three ports, a first port of said 2 x 2 optical coupler coupled to a first end of said loop of optical fiber, a second port of said 2 x 2 optical coupler coupled to a second end of said loop of optical fiber, and a third port of said 2 x 2 optical coupler coupling said Stokes beam into and out of said loop of optical fiber.

41. The spread spectrum waveform generator of claim 39, wherein said optical path producing said Stokes beam comprises a length of optical fiber.

42. The spread spectrum waveform generator of claim 39, wherein said optical amplification path comprises one or more optical amplifiers or one or more optical amplifiers and one or more variable optical attenuators.

43. The spread spectrum waveform generator of claim 39, wherein a fraction of said optical signal is directed to said optical path producing said Stokes beam and said optical path producing said Stokes beam has a length sufficient to ensure a Stokes seed is generated.

44. The spread spectrum waveform generator of claim 39, wherein said optical path producing said Stokes beam has one or more optical amplifiers.

45. The spread spectrum waveform generator of claim 40, wherein the coupling strength of said 2 X 2 optical coupler is adjustable.

46. The spread spectrum waveform generator of claim 39, wherein said second optical branch further comprises an optical isolator blocking said Stokes beam from coupling into said common path.

47. The spread spectrum waveform generator of claim 39, wherein said second optical branch further comprises a third optical circulator disposed between said second splitter output and said input to said main optical fiber.

48. A method of generating a spread spectrum waveform, the method comprising the steps of:

(a) generating a multi-tone optical comb as a series of RF comb lines on an optical carrier;

(b) generating a single tone frequency translation reference; and

(c) optically combining the optical comb with the frequency translation reference to generate a lightwave waveform suitable for subsequent heterodyning.

49. The method of claim 48, wherein the method comprises a method of generating an agile spread spectrum waveform and the single tone frequency translation reference comprises a wavelength-tunable single tone frequency translation reference.

50. The method of claim 48, wherein the method comprises a method of generating a frequency-modulated spread spectrum waveform and wherein the single tone frequency translation reference comprises a wavelength-modulated single tone frequency translation reference and the multi-tone optical comb is generated by an oscillator.

51. The method of claim 48 further including the step of heterodyning the lightwave waveform.

52. The method of claim 48 further wherein the step of heterodyning is performed by at least one photodetector.

53. The method of claim 48 wherein the multi-tone optical comb is generated by a photonic oscillator and further including the following steps:

(i) optically delaying the comb in a first loop for spacing comb lines in the comb;

(ii) optically delaying the comb in a second loop line for noise reduction, a second optical delay caused by step (ii) being longer than a first optical delay caused by step (i);

(iii) photodetecting the delayed comb; and

(iv) using the delayed comb in an optical intensity modulator to modulate an output of a laser to thereby generate said multi-tone optical comb as a series of RF comb lines on an optical carrier.

54. The method of claim 53 wherein a loop common portion further includes an amplifier for amplifying the comb and a band pass filter for establishing a bandwidth of the comb.

55. The method of claim 54 wherein the amplifying is performed electronically.

56. The method of claim 53 wherein a loop common portion includes a band pass filter for establishing a band width of the comb and further including a step of optically amplifying the comb in at least one of the first and second loops.

57. The method of claim 53 further including the step of compensating for environmental changes by changing the amount of at least one of the first and second optical delays.

58. The method of claim 57 wherein the step of compensating for environmental changes by changing an amount of at least one of the optical delays is performed by comparing frequency or phase of one comb line in the comb with a reference and adjusting a length and/or an optical refractive index of at least one optical delay line carrying the comb.

59. The method of claim 58 wherein the adjusting step adjusts the length and/or the optical refractive index of first and second optical delay lines.

60. The method of claim 57 wherein the step of compensating for environmental changes by changing an amount of at least one of the optical delays is performed by comparing frequency or phase of one comb line in the comb with a reference and adjusting a phase of the comb.

61. The method of claim 53 further including the step of seeding the photonic oscillator to initiate the comb.

62. The method of claim 53 wherein the second optical delay is more than 40 times longer than the first optical delay.

63. The method of claim 48 further including the step of intensity modulating the comb with an optical intensity modulator responsive to an RF input signal and to the series of RF comb lines on the optical carrier for modulating said lightwave waveform.

64. The method of claim 63 wherein the RF input signal applies a pulsed code or polyphased codes to the optical intensity modulator.

65. The method of claim 48 further including the step of modulating the intensity of the comb and the frequency translation reference with an optical intensity modulator responsive to an RF input signal and to the series of RF comb lines on the optical carrier and to the frequency translation reference for modulating said lightwave waveform.

66. The method of claim 65 wherein the RF input signal applies a pulsed code or polyphased codes to the optical intensity modulator.

67. The method of claim 48, wherein the step of generating a multi-tone optical comb comprises:

modulating an optical signal from a laser with an optical modulator to provide a modulated optical signal;

delaying said modulated optical signal in a first optical branch to provide a first delayed optical signal;

propagating said modulated optical signal in a forward direction in a second optical branch to provide a second delayed optical signal;

generating Stokes light from said modulated optical signal;

injecting said Stokes light into said second optical branch so that said Stokes light propagates in a reverse direction to said modulated optical signal in said second optical branch, wherein said Stokes light acts as a seed for stimulated Brillouin scattering in said second optical branch;

photodetecting said first delayed optical signal and said second delayed optical signal to produce an electrical signal; and

controlling said optical modulator with said electrical signal.

68. The method of claim 67, wherein said first optical branch comprises optical fiber and said second optical branch comprises optical fiber.

69. The method of claim 67, wherein said method further comprises at least one step of the group of steps consisting of a step of amplifying said electrical signal, a step of band pass filtering the electrical signal, and a step of phase shifting the electrical signal.

70. The method of claim 67 further comprising the steps of

directing said modulated optical signal to said first optical branch from a first output of a variable optical coupler;

directing said modulated optical signal to said second optical branch from a second output of said variable optical coupler;

providing said multi-tone optical comb from a third output of said variable optical coupler; and

controlling a output power level of at least one output of said first output, said second output, and said third output.

71. The method of claim 67 wherein at least one optical branch of the first and second optical branches comprises at least one element of the group of elements consisting of an optical amplifier and a variable optical attenuator.

72. The method of claim 67, wherein said second optical branch comprises a main optical fiber and said step of generating Stokes light comprises the steps of:

directing said modulated optical signal into said main optical fiber, wherein said Stokes light is produced by stimulated Brillouin scattering in said main optical fiber;

directing said reverse propagating Stokes light from said second optical branch to an optical amplification path with an optical circulator; and

amplifying said Stokes light.

73. The method of claim 72 further comprising the step of variably attenuating said Stokes light.

74. The method of claim 72 further comprising the step of filtering a component of Stokes light generated by said reverse propagating Stokes light.

75. The method of claim 67, wherein said step of generating Stokes light comprises the steps of:

directing said modulated optical signal to a third optical branch, wherein said Stokes light is produced by stimulated Brillouin scattering in said third optical branch; and

coupling said Stokes light out of said third optical branch.

76. The method of claim 75 further comprising the step of amplifying said Stokes light prior to injecting said Stokes light into said second optical branch.

77. The method of claim 75, wherein said third optical branch comprises a recirculating ring.

78. The method of claim 75, wherein said third optical branch comprises an optical fiber.

79. The method of claim 75, further comprising filtering said modulated optical signal to reduce the amount of power of said modulated optical signal coupled into said third optical branch.

80. The method of claim 39 wherein step (b) includes providing two slave lasers and optically injection locking the two slave lasers to an amplitude or intensity modulated master laser, the master laser being driven by a frequency-modulated signal.

81. The method of claim 80 wherein an output of the master laser comprises an optical carrier and one or more amplitude or intensity modulation sidebands, the frequency of the one or more sidebands being modulated in response to the frequency-modulated signal.

82. The method of claim 81 wherein one of the two slave lasers is a single tone laser that is optically injection locked to the optical carrier produced by the master laser.

83. The method of claim 82 wherein the other of the two slave lasers is a variable tone laser that is optically injection locked to one of the one or more amplitude or intensity modulation sidebands produced by the master laser.

84. The method of claim 83 wherein the multi-tone optical comb is generated by a photonic oscillator and further including the following steps:
(i) optically delaying the comb in a first loop for spacing comb lines in the comb;
(ii) optically delaying the comb in a second loop line for noise reduction, a second optical delay caused by step (ii) being longer than a first optical delay caused by step (i);
(iii) photodetecting the delayed comb; and
(iv) using the delayed comb in an optical intensity modulator to modulate an output of the single tone laser to thereby generate said multi-tone optical comb as a series of RF comb lines on the first optical carrier.

85. The method of claim 80 wherein the frequency-modulated signal is a single value invertible function.

86. The method of claim 85 wherein the single value invertible function is non-continuous.

87. A multi-tone photonic oscillator comprising:

a laser producing an optical carrier wave;

a first optical branch comprising a first optical delay element;

a second optical branch comprising a main optical fiber having a forward direction of light propagation;

a third optical branch, said third optical branch providing a Stokes beam to said second optical branch, said Stokes beam propagating in said main optical fiber in a direction opposite to said forward direction of light propagation; and

a common path, said common path comprising:

an optical portion having an optical modulator receiving said optical carrier wave and providing an optical signal to said first optical branch, said second optical branch, and said third optical branch; and,

an electrical portion having at least one photodetector coupled to said first optical branch and said second optical branch, said at least one photodetector producing an electrical signal coupled to said optical modulator.

88. The multi-tone photonic oscillator of claim 87, wherein said electrical portion comprises:

a first photodetector coupled to said first optical branch;

a second photodetector coupled to said second optical branch;

an electrical combiner coupled to said first photodetector and said second photodetector and producing a combined electrical output; and

a bandpass filter receiving said combined electrical output and providing a filtered electrical signal to said optical modulator.

89. The multi-tone photonic oscillator of claim 87 wherein said common path further comprises at least one element of the group of elements consisting of an electrical amplifier, an optical amplifier, an electrical phase shifter, and an optical phase shifter.

90. The multi-tone photonic oscillator of claim 87 wherein said common path further comprises a variable optical coupler, said variable optical coupler having an input receiving said optical signal, and having a first adjustable output coupled to said first

optical branch, a second adjustable output coupled to said second optical branch, and a third adjustable output.

91. The multi-tone photonic oscillator of claim 87, wherein at least one optical branch of said first and second optical branches further comprises at least one element of the group of elements consisting of an optical amplifier and a variable optical attenuator.

92. The multi-tone photonic oscillator of claim 87, wherein said first optical delay element comprises optical fiber.

93. The multi-tone photonic oscillator of claim 87, wherein said third optical branch comprises an optical notch filter that reduces a component of Stokes light that is generated by said Stokes beam.

94. The multi-tone photonic oscillator of claim 87, wherein said third optical branch comprises an optical notch filter that reduces the amount of power of said optical carrier coupled into said third optical branch.

95. The multi-tone photonic oscillator of claim 87, wherein said Stokes beam is produced by stimulated Brillouin scattering in said main optical fiber and said main optical fiber has an input and an output and said third optical branch comprises:

an optical amplification path, said optical amplification path having an input and an output;

a first optical circulator, said first optical circulator coupling said optical signal to said input of said main optical fiber and coupling said Stokes beam to said input of said optical amplification path; and

a second optical circulator, said second optical circulator coupling said output of said optical amplification path to said main optical fiber and coupling said output of said main optical fiber to said at least one photodetector.

96. The multi-tone photonic oscillator of claim 95, wherein said optical amplification path comprises one or more optical amplifiers or one or more optical amplifiers and one or more variable optical attenuators.

97. The multi-tone photonic oscillator of Claim 87, wherein said main optical fiber has an input and an output and wherein said second optical branch further comprises an optical splitter having a first splitter output and a second splitter output, the second splitter output directing said optical signal to said input of said main optical fiber, and wherein said third optical branch comprises:

an optical amplification path having an input and an output;

an optical path producing said Stokes beam by stimulated Brillouin scattering;

a first optical circulator having at least three ports, wherein a first port of said first optical circulator is coupled to said first splitter output and a second port of said first optical circulator coupled to said input of said optical amplification path, and a third port of said first optical circulator is coupled to said optical path producing said Stokes beam, said first optical circulator directing said optical signal to said optical path producing said Stokes beam and directing said Stokes beam to said optical amplification path; and,

a second optical circulator, said second optical circulator coupling said output of said optical amplification path to said main optical fiber and coupling said output of said main optical fiber to said at least one photodetector.

98. The multi-tone photonic oscillator of claim 97, wherein said optical path producing said Stokes beam comprises:

a loop of optical fiber; and

a 2 x 2 optical coupler having at least three ports, a first port of said 2 x 2 optical coupler coupled to a first end of said loop of optical fiber, a second port of said 2 x 2 optical coupler coupled to a second end of said loop of optical fiber, and a third port of said 2 x 2 optical coupler coupling said Stokes beam into and out of said loop of optical fiber.

99. The multi-tone photonic oscillator of claim 97, wherein said optical path producing said Stokes beam comprises a length of optical fiber.

100. The multi-tone photonic oscillator of claim 97, wherein said optical amplification path comprises one or more optical amplifiers or one or more optical amplifiers and one or more variable optical attenuators.

101. The multi-tone photonic oscillator of claim 97, wherein a fraction of said optical signal is directed to said optical path producing said Stokes beam and said optical path producing said Stokes beam has a length sufficient to ensure a Stokes seed of sufficient power is generated.

102. The multi-tone photonic oscillator of claim 97, wherein said optical path producing said Stokes beam has one or more optical amplifiers.

103. The multi-tone photonic oscillator of claim 98, wherein the coupling strength of said 2 x 2 optical coupler is adjustable.

104. The multi-tone photonic oscillator of claim 97, wherein said second optical branch further comprises an optical isolator blocking said Stokes beam from coupling into said common path.

105. The multi-tone photonic oscillator of claim 97, wherein said second optical branch further comprises a third optical circulator disposed between said second splitter output and said input to said main optical fiber.

106. A method of generating a multi-tone optical comb, the method comprising the steps of:
modulating an optical signal from a laser with an optical modulator to provide a modulated optical signal;
delaying said modulated optical signal in a first optical branch to provide a first delayed optical signal;

propagating said modulated optical signal in a forward direction in a second optical branch to provide a second delayed optical signal;

generating Stokes light from said modulated optical signal;

injecting said Stokes light into said second optical branch so that said Stokes light propagates in a reverse direction to said modulated optical signal in said second optical branch, wherein said Stokes light acts as a seed for stimulated Brillouin scattering in said second optical branch;

photodetecting said first delayed optical signal and said second delayed optical signal to produce an electrical signal; and

controlling said optical modulator with said electrical signal.

107. The method of claim 106, wherein said first optical branch comprises optical fiber and said second optical branch comprises optical fiber.

108. The method of claim 106, wherein said method further comprises at least one step of the group of steps consisting of a step of amplifying said electrical signal, a step of band pass filtering the electrical signal, and a step of phase shifting the electrical signal.

109. The method of claim 106 further comprising the steps of

directing said modulated optical signal to said first optical branch from a first output of a variable optical coupler;

directing said modulated optical signal to said second optical branch from a second output of said variable optical coupler;

providing said multi-tone optical comb from a third output of said variable optical coupler; and

controlling a output power level of at least one output of said first output, said second output, and said third output.

110. The method of claim 106 wherein at least one optical branch of the first and second optical branches comprises at least one element of the group of elements consisting of an optical amplifier and a variable optical attenuator.

111. The method of claim 106, wherein said second optical branch comprises a main optical fiber and said step of generating Stokes light comprises the steps of:

directing said modulated optical signal into said main optical fiber, wherein said Stokes light is produced by stimulated Brillouin scattering in said main optical fiber;

directing said reverse propagating Stokes light from said second optical branch to an optical amplification path with an optical circulator; and

amplifying said Stokes light.

112. The method of claim 111 further comprising the step of variably attenuating said Stokes light.

113. The method of claim 111 further comprising the step of filtering a component of Stokes light generated by said reverse propagating Stokes light.

114. The method of claim 106, wherein said step of generating Stokes light comprises the steps of:

directing said modulated optical signal to a third optical branch, wherein said Stokes light is produced by stimulated Brillouin scattering in said third optical branch; and

coupling said Stokes light out of said third optical branch.

115. The method of claim 114 further comprising the step of amplifying said Stokes light prior to injecting said Stokes light into said second optical branch.

116. The method of claim 114, wherein said third optical branch comprises a recirculating ring.

117. The method of claim 114, wherein said third optical branch comprises an optical fiber.

118. The method of claim 114, further comprising filtering said modulated optical signal to reduce the amount of power of said modulated optical signal coupled into said third optical branch.

119. A frequency-modulated spread spectrum waveform generator comprising:

(a) a generator for generating a frequency modulated optical waveform;

(b) a comb generator for generating an optical comb;

(c) an optical coupler combining frequency modulated optical waveform and the optical comb; and

(d) at least one photodetector for heterodyning the output of the optical coupler.

120. The frequency-modulated spread spectrum waveform generator of claim 119, wherein the comb generator comprises multiple loops including:

(i) a first optical delay line in a first loop for spacing a comb generated by the multi-tone optical comb generator;

(ii) a second optical delay in a second loop line for noise reduction, the second delay line being longer than the first optical delay line;

(iii) at least one photo detector connected to the first and second delay lines; and

(iv) an optical intensity modulator in a loop portion common to the first and second loops for driving the first and second optical delay lines.

121. The frequency-modulated spread spectrum waveform generator of claim 120 wherein the loop common portion further includes an amplifier and a band pass filter.

122. The frequency-modulated spread spectrum waveform generator of claim 121 wherein the amplifier is an electronic amplifier.

123. The frequency-modulated spread spectrum waveform generator of claim 120 wherein the loop common portion further includes a band pass filter and wherein at least one of the first and second loops includes an optical amplifier therein.

124. The frequency-modulated spread spectrum waveform generator of claim 120 further including means for compensating for environmental changes affecting an optical delay of at least one of the first and second optical delay lines.

125. The frequency-modulated spread spectrum waveform generator of claim 124 wherein the means for compensating for environmental changes affecting the optical delay of at least one of the first and second optical delay lines comprises an apparatus for adjusting the length and/or an optical refractive index of at least one of the first and second optical delay lines and a feedback circuit including a tone selection filter to the loop common portion and a mixer for mixing the output of the tone selection filter with a reference signal, an output of the mixer being operatively coupled to the length adjusting apparatus.

126. The frequency-modulated spread spectrum waveform generator of claim 125 wherein the tone selection filter is coupled to the optical intensity modulator.

127. The frequency-modulated spread spectrum waveform generator of claim 126 wherein the optical intensity modulator is electro-absorption modulator having an electrical output coupled to the tone selection filter.

128. The frequency-modulated spread spectrum waveform generator of claim 125 wherein the adjusting apparatus adjusts the length and/or an optical refractive index of both of the first and second optical delay lines.

129. The frequency-modulated spread spectrum waveform generator of claim 124 wherein the means for compensating for environmental changes affecting the length of at least one of the first and second optical delay lines comprises a phase shifter disposed in the loop common portion and a feedback circuit including a tone selection filter coupled to the loop common portion and a mixer for mixing the output of the tone selection filter with a reference signal, an output of the mixer being operatively coupled to the phase shifter.

130. The frequency-modulated spread spectrum waveform generator of claim 129 wherein the tone selection filter is coupled to the optical intensity modulator.

131. The frequency-modulated spread spectrum waveform generator of claim 130 wherein the optical intensity modulator is an electro-absorption modulator having an electrical output coupled to the tone selection filter.

132. The frequency-modulated spread spectrum waveform generator of claim 120 further including a injection seeding circuit for seeding the photonic oscillator.

133. The frequency-modulated spread spectrum waveform generator of claim 120 wherein the second optical delay line is more than 40 times longer than is the first optical delay line.

134. The frequency-modulated spread spectrum waveform generator of claim 120 further including an optical intensity modulator, the optical intensity modulator being responsive to an RF input signal and to the series of RF comb lines on the optical carrier generated by the photonic oscillator for generating a optical signal which is applied to said photo detector.

135. The frequency-modulated spread spectrum waveform generator of claim 120 further including an optical coupler responsive to an RF input signal, the optical coupler being connected to receive the series of RF comb lines on the optical carrier generated by the photonic oscillator and the frequency translation reference generated by the second laser, the optical coupler being connected either upstream or downstream of the optical intensity modulator which is responsive to the RF input signal.

136. The frequency-modulated spread spectrum waveform generator of claim 135 wherein the RF input signal includes a pulsed code or polyphased codes.

137. The frequency-modulated spread spectrum waveform generator of claim 119, wherein the generator for generating a frequency modulated optical waveform comprises two slave

lasers and an amplitude or intensity modulated master laser for optically injection locking the two slave lasers to the master laser, the master laser being driven by a frequency-modulated signal.

138. The frequency-modulated spread spectrum waveform generator of claim 137 wherein an output of the master laser comprises an optical carrier and one or more amplitude or intensity modulation sidebands, the frequency of the one or more sidebands being modulated in response to the frequency-modulated signal.

139. The frequency-modulated spread spectrum waveform generator of claim 138 wherein one of the two slave lasers is a single tone laser that is optically injection locked to the optical carrier produced by the master laser.

140. The frequency-modulated spread spectrum waveform generator of claim 139 wherein the other of the two slave lasers is a variable tone laser that is optically injection locked to one of the one or more amplitude or intensity modulation sidebands produced by the master laser.

141. The frequency-modulated spread spectrum waveform generator of claim 137 wherein the frequency-modulated signal is a single value invertible function.

142. The frequency-modulated spread spectrum waveform generator of claim 141 wherein the single value invertible function is non-continuous.

143. A method of generating a spread spectrum waveform comprising:

(a) generating a multi-tone optical comb as a series of RF comb lines on a first optical carrier;

(b) generating a wavelength-modulated optical frequency translation reference from a second optical carrier; and

(c) heterodyning the optical comb and the optical frequency translation reference to generate the spread spectrum waveform.

144. The method of claim 143, wherein the wavelength-modulated optical frequency translation reference comprises a single tone optical signal having a wavelength that is modulated from a first time instance to a second time instance.

145. The method of claim 144 further wherein heterodyning is performed by at least one photodetector.

146. The method of claim 145 wherein the multi-tone optical comb is generated by a photonic oscillator and further including the following steps:

(i) optically delaying the optical comb in a first loop for spacing RF comb lines in the comb;

(ii) optically delaying the comb in a second loop line for noise reduction, a second optical delay caused by step (ii) being longer than a first optical delay caused by step (i);

(iii) photodetecting the delayed comb; and

(iv) using the delayed comb in an optical intensity modulator to modulate an output of a laser to thereby generate said multi-tone optical comb as a series of RF comb lines on an optical carrier.

147. The method of claim 146 wherein a loop common portion further includes an amplifier for amplifying the comb and a band pass filter for establishing a bandwidth of the comb.

148. The method of claim 147 wherein the amplifying step is performed electronically.

149. The method of claim 146 wherein a loop common portion includes a band pass filter for establishing a band width of the comb and further including a step of optically amplifying the comb in at least one of the first and second loops.

150. The method of claim 146 further including the step of compensating for environmental changes by changing the amount of at least one of the first and second optical delays.

151. The method of claim 150 wherein the step of compensating for environmental changes by changing an amount of at least one of the optical delays is performed by comparing frequency or phase of one comb line in the comb with a reference and adjusting a length and/or an optical refractive index of at least one optical delay line carrying the comb.

152. The method of claim 151 wherein the adjusting step adjusts the length and/or an optical refractive index of first and second optical delay lines.

153. The method of claim 150 wherein the step of compensating for environmental changes by changing an amount of at least one of the optical delays is performed by comparing frequency or phase of one comb line in the comb with a reference and adjusting a phase of the comb.

154. The method of claim 146 further including the step of seeding the photonic oscillator to initiate the comb.

155. The method of claim 146 wherein the second optical delay is more than 40 times longer than the first optical delay.

156. The method of claim 143 further including the step of intensity modulating the comb with an optical intensity modulator responsive to an RF input signal and to the series of RF comb lines on the optical carrier for modulating said lightwave waveform.

157. The method of claim 156 wherein the RF input signal applies a pulsed code or polyphased codes to the optical intensity modulator.

158. The method of claim 157 wherein the spread spectrum waveform is a frequency modulated multi-tone waveform suitable for a radar system.

159. The method of claim 143 further including the step of modulating the intensity of the comb and the frequency translation reference with an optical intensity modulator

responsive to an RF input signal and to the series of RF comb lines on the optical carrier and to the frequency translation reference for modulating said spread spectrum waveform.

160. The method of claim 159 wherein the RF input signal applies a pulsed code or polyphased codes to the optical intensity modulator.

161. The method of claim 143 wherein step (b) includes providing two slave lasers and optically injection locking the two slave lasers to an amplitude or intensity modulated master laser, the master laser being driven by a frequency-modulated signal.

162. The method of claim 161 wherein an output of the master laser comprises an optical carrier and one or more amplitude or intensity modulation sidebands, the frequency of one or more sidebands being modulated in response to the frequency-modulated signal.

163. The method of claim 162 wherein one of the two slave lasers is a single tone laser that is optically injection locked to the optical carrier produced by the master laser.

164. The method of claim 163 wherein the other of the two slave lasers is a variable tone laser that is optically injection locked to one of the on or more amplitude or intensity modulation sidebands produced by the master laser.

165. The method of claim 164 wherein the multi-tone optical comb is generated by a photonic oscillator and further including the following steps:

(i) optically delaying the comb in a first loop for spacing comb lines in the comb;

(ii) optically delaying the comb in a second loop line for noise reduction, a second optical delay caused by step (ii) being longer than a first optical delay caused by step (i);

(iii) photodetecting the delayed comb; and

(iv) using the delayed comb in an optical intensity modulator to modulate an output of the single tone laser to thereby generate said multi-tone optical comb as a series of RF comb lines on the first optical carrier.

166. The method of claim 161 wherein the frequency-modulated signal is a single value invertible function.

167. The method of claim 166 wherein the single value invertible function is non-continuous.

168. A frequency-modulated spread spectrum waveform generator comprising:

(a) a frequency modulated comb generator for generating a relatively fine-spaced optical comb; (b) a comb generator for generating a relatively coarse-spaced optical comb;

(c) an optical coupler combining the relatively fine-spaced optical comb and the relatively coarse-spaced optical comb; and

(d) at least one photodetector for heterodyning the output of the optical coupler.

169. A receiver pre-processor for pulse compression of multi-tone received and reference waveforms, the pre-processor comprising:

means for temporal division of the multi-tone received and reference waveforms into series of temporal segments; and

means for repeatedly comparing multiple time-staggered sets of the segments of the reference multi-tone waveform with the segments of the received multi-tone waveform.

170. The receiver pre-processor of claim 169 wherein the means for temporal division of the multi-tone received and reference waveforms into series of segments comprises first and second tapped delay lines, with each delay line being associated with one of the received and reference waveforms and having a series of taps corresponding to the number of temporal segments of the associated one of the received and reference waveforms.

171. The receiver pre-processor of claim 170 wherein the means for repeatedly comparing multiple time-staggered sets of the segments of the reference multi-tone waveform with the segments of the received multi-tone waveform comprises comparators and switches,

the taps of the delay line associated with receive waveform each feeding one of said comparators and the taps of the delay line associated with reference waveform each feeding, via a pair of said switches, a switch-selected one of the comparators to thereby present multiple time-delayed copies of a particular segment of the reference waveform to a comparator that is associated with that segment for continually comparing the received multi-tone waveform with a spatially segmented version of the reference multi-tone waveform.

172. The receiver pre-processor of claim 171 wherein the comparators each include at least one filter to spectrally separate multiple tones of the reference multi-tone waveform and received multi-tone waveform for comparison by RF mixing.

173. The receiver pre-processor of claim 172 wherein comparison by the comparators occurs either on a tone-by-tone basis or with subsets of tones.

174. The receiver pre-processor of claim 172 wherein the filters have a periodic frequency spectrum, the filters comprising two sets of filters with each set having a different spectral period.

175. A method of generating a dense-spectrum waveform comprising the steps of:
   i. generating a frequency comb of relatively fine-spaced tones;
   ii. generating a frequency comb of relatively coarse-spaced tones; and
   iii. interleaving the fine-spaced tones and the coarse-spaced tones by optical heterodyning.

176. The method of claim 175 wherein the relatively fine-spaced tones are generated by a wavelength-tunable laser having a period frequency variation.

177. The method of claim 176 wherein the relatively coarse-spaced tones are generated by a photonic oscillator comprising a multi-tone comb generator for generating a series of RF comb lines on an optical carrier.

178. The method of claim 177 wherein the interleaving of the relatively fine-spaced tones and the relatively coarse-spaced tones is accomplished by using a photo detector to optically heterodyne an output of the wavelength-tunable laser with an output of the photonic oscillator.

179. The method of claim 178 further including means for intensity and/or phase modulating the dense spread-spectrum waveform to thereby produce a pulse coded or polyphase waveform suitable for a radar system.